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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Jack O. Chu, et al. **Examiner:** Johannes P. MONDT
Serial No: 10/775,514 **Art Unit:** 2826
Filed: February 10, 2004 **Docket:** YOR920010308US3 (16315B)
For: EPITAXIAL AND POLYCRYSTALLINE GROWTH OF $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ AND $\text{Si}_{1-y}\text{C}_y$ ALLOY LAYERS ON Si BY UHV-CVD **Dated:** July 20, 2006

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**DECLARATION UNDER 37 C.F.R. §1.132 OF DR. JACK OON CHU
IN U.S. PATENT APPLICATION NO. 10/775,514**

Sir:

I, Dr. Jack Oon Chu, hereby declare that:

(1) I am one of the inventors for U.S. Patent Application No. 10/775,514 filed on February 10, 2004 for "EPITAXIAL AND POLYCRYSTALLINE GROWTH OF $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ AND $\text{Si}_{1-y}\text{C}_y$ ALLOY LAYERS ON Si BY UHV-CVD" (hereinafter "Application"), which describes and claims layered structures that each comprise an interface that is defined by an upper surface of a single crystalline Si layer and one or more carbon-doped single crystalline layers (such as SiC or SiGeC) and have an abrupt change in C concentration of more than 1×10^{18} atoms/cc over a layer thickness in the range from about 6 Å to about 60 Å.

(2) Such layered structures, as described in paragraph (1) hereinabove, have been fabricated using an ultra high vacuum chemical vapor deposition (UHV-CVD) process described by U.S. Patent No. 5,906,680 to B.S. Meyerson entitled "Method and Apparatus for Low Temperature, Low Pressure Chemical Vapor Deposition of Epitaxial Silicon Layers" (hereinafter "Meyerson").

(3) Specifically, the UHV-CVD process was carried out in a quartz CVD reactor at a growth temperature as low as about 500°C and a growth pressure as low as about $2-3 \times 10^{-3}$ torr to form layers of single crystal silicon-containing materials over Si substrates. The deposition rate of such single crystal silicon-containing layers was approximately from about one (1) monolayer to about ten (10) monolayers per minute. Each monolayer had a thickness of about 6Å.

(4) Carbon doping was carried out intermittently, so as to form alternating single crystal silicon-containing layers with and without carbon dopant. Specifically, ethylene gas having a purity grade of about 99.999% was used as the carbon precursor during the carbon doping. Before the deposition process, turbo pumps were used to pump out the contents of the quartz CVD reactor and to achieve an initial base pressure of about $1-5 \times 10^{-9}$ torr. Such turbo pumps continued to operate at high pumping speeds throughout the deposition process, so that the contents of the quartz CVD reactor were continuously replaced by inflowing precursor gases.

(5) The UHV-CVD process as described hereinabove in paragraphs (3)-(4) showed no background carbon contamination or "memory effect," which can be contributed to several factors. First, carbon as a dopant species has relatively low background contamination or "memory effect," in comparison with other dopant species such as phosphorus. Second, use of

the high purity ethylene gas as the carbon precursor significantly reduced the background carbon contamination, in comparison with deposition processes using liquid carbon precursors such as methylsilane. Third, the walls of the quartz CVD reactor absorbed little or no carbon or carbon precursor, thereby further reducing the background carbon contamination. Fourth, use of the turbo pumps allowed immediate adjustment of the ethylene concentration in the quartz CVD reactor (and consequently, the carbon doping level in the deposited single crystal layers) by controlling the ethylene flow rate. Specifically, when inflow of the ethylene gas was turned off, the partial pressure of ethylene in the quartz CVD reactor was immediately reduced to less than 10^{-8} torr, and termination of the carbon doping was effectuated thereby, with no background carbon contamination for subsequent deposition. However, when the ethylene precursor gas was turned back on, the partial pressure of ethylene immediately increased to the level suitable for carbon doping. Consequently, carbon concentration changes in the deposited single crystal layers were immediately effectuated by changing the ethylene flow rate into the quartz CVD chamber, with no background carbon contamination or "memory" effect.

(6) The lack of background carbon contamination or "memory" effect was substantiated by the experimental data contained in Table 1 of the specification of the Application, which shows that once the ethylene precursor gas was turned off, there was no carbon contamination or "memory" effect for any subsequent growth, and the carbon concentration in the subsequently grown epitaxial layers was reduced to a level that was below or equivalent to the 1×10^{17} atoms/cc detection limit of the secondary ion mass spectrometric (SIMS) measurement for carbon analysis.

(7) The lack of background carbon contamination or "memory" effect was also demonstrated, although indirectly, by the SIMS results from Figs. 1, 3, and 4 of the specification of the Application. The "valley" regions of the carbon concentration curves in Figs. 1, 3, and 4 were formed when the ethylene precursor gas was turned off. If background carbon contamination or "memory" effect existed, the carbon concentrations of such "valley" regions would increase significantly over time, because each cycle of carbon doping would leave a certain amount of carbon residue in the quartz CVD reactor. However, the carbon concentrations of such "valley" regions as shown in Figs. 1, 3, and 4 remained substantially the same after repeated cycles of carbon doping, indicating that there was no background carbon contamination or "memory" effect each time after the ethylene precursor gas was turned off.

(8) Therefore, a layered structure that comprised alternating layers of single crystal silicon-containing materials with and without carbon dopant was formed by the above-described UHV-CVD process, and interfaces between the single crystal layers with carbon dopant and the single crystal layers without carbon dopant were characterized by an abrupt change in carbon concentration of more than 1×10^{18} atoms/cc over a layer thickness in the range from about 6 Å to about 60 Å. Such an abrupt carbon concentration change was conjunctively effectuated by the monolayer-by-monolayer deposition of the single crystal layers, the immediate adjustment of ethylene precursor concentration in the quartz CVD reactor, and the lack of background carbon contamination or "memory" effect.

(9) However, I am not aware of any currently available analytical tool can be used to show such an abrupt carbon concentration change, although the change could be readily inferred from the

deposition rate of the single crystal layers, the immediately adjustment of ethylene concentration in the quartz CVD reactor, and the lack of background carbon contamination or "memory" effect.

(10) Secondary ion mass spectrometry (SIMS) has a very limited depth resolution, e.g., about 125 Å per decade at the time of analysis. Therefore, the SIMS results shown in Figure 1 of the Application only illustrated the total or ultimate carbon concentration change from a carbon-doped single crystal layer to an adjacent undoped layer, but it could not show the abruptness of the carbon concentration change occurred at the 6-60Å interface between such layers, due to the limited depth resolution of the SIMS tool.

(11) Transmission electron microscopy (TEM) only measures the strain contrast between adjacent single crystal layers, which can be caused by different doping levels therein. When the carbon concentrations in the single crystal layers are below 2 atomic%, the strain contrast between adjacent single crystal layers of different carbon doping levels is too low to be detected by the TEM analysis. Only when the carbon concentrations in the single crystal layers reach about 2 atomic%, the strain contrast between adjacent single crystal layers is high enough to be detected by the TEM analysis. Unfortunately, such high carbon concentrations in the single crystal layers will lead to formation of significant defect in the crystal structure of the layers, which then do not meet the material requirements for high quality devices. Further, the TEM data can only be used to indicate the approximate positions of the interfaces between adjacent single crystal layers of different carbon doping levels, but it cannot show the actual magnitude or degree of carbon concentration changes occurred at such interfaces.

(12) Prior to the invention described in this Application, carbon concentration changes between adjacent single crystal silicon-containing layers have never been achieved to the level of more than 1×10^{18} atoms/cc over a layer thickness in the range from about 6 Å to about 60 Å, due to several reasons. First, such an abrupt carbon concentration change severely disrupted the crystal lattice during epitaxial growth and formed defects in the deposited layers. Second, when the carbon concentration in a silicon-containing layer exceeded a critical value, i.e., the equilibrium solid solubility, beta-SiC started to precipitate out of the crystal lattice. Consequently, polycrystalline SiC layers were formed, instead of single crystalline SiC layers.

(13) The invention as described in this Application successfully achieved the above-described abrupt carbon concentration change, but without affecting the single crystalline characteristic or quality of the deposited SiC layers. Such a success was enabled by employment of the UHV-CVD process as described hereinabove in paragraphs (3)-(4).

(14) I hereby declare that all statements made herein, of my own knowledge, are true, that all statements made on information and belief are believed to be true, and that these statements are made with the knowledge that willful false statements and the like so made may be punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the U.S. Code and that such willful false statements may jeopardize the validity of the application or any patent issued therefrom.


Jack Oon Chu7-20-06
Date